Particle Physics and Cosmology at LBNL:

Status and Outlook

November 2004

1 Executive Summary

The High Energy Physics program at LBNL, comprising the entirety of the Physics Division and a portion of the Accelerator and Fusion Research Division, brings a unique combination of university and laboratory resources to the pursuit of high energy physics. This document provides a brief summary of the current research program in the Physics Division, our relationship to other high-energy physics institutions, and our plans for future work

The Berkeley HEP program makes essential contributions in four broad scientific areas: at the energy frontier through the search for the origins of mass; in the quark flavor mixing sector through the search for the mechanisms of CP violation; in the lepton flavor sector through the study of flavor oscillations of reactor and solar neutrinos; and in particle astrophysics through the study of dark matter and dark energy. These flagship science efforts are complemented by theoretical studies, and the activities of the Particle Data Group. The science priorities of the Berkeley effort are directly aligned with those of the national program.

In each of our four major efforts, BaBar, CDF, ATLAS and SNAP, the Physics Division makes significant and essential contributions. In addition, we lead the Particle Data Group and the US KamLAND collaboration. LBNL's historical role has been one of physics from 'start to finish'. We participate in the conception, design, construction, commissioning, operation, physics analysis and preparation of upgrades in our experiments. The support and facilities of the Laboratory allow us to carry these roles very effectively in a way not possible even in large university groups.

The future program at Berkeley is described in the Physics Division Strategic Plan. Our physics program will increasingly focus on discovery of the origins of mass, and on determining the nature of the Dark Energy. We plan to maintain the diversity of our program with a complementary effort in neutrino physics. ATLAS and SNAP have become the largest components of the Physics Division program. Neutrino experiments will be a joint effort with the Nuclear Science Division. R&D efforts for both instrumentation and computing will be ongoing. The Linear Collider accelerator efforts will grow commensurate with the national linear collider collaboration.

Detailed staffing and budget plans for the particle cosmology efforts and origin of mass efforts are outlined in Appendices I and II. Details of current funding are presented in Appendix III.

LBNL has been able to contribute major advances such as the TPC, high-resistivity CCDs and high performance superconducting cable because in the past it was able to set aside resources for fundamental research not directed towards an existing project. It has been able to provide the IC design that made possible the SVX and its descendents because it maintained a team of innovative chip designers at the Lab. These capabilities can survive only if they are provided adequate and sustained funding.

Berkeley has helped to shape high-energy physics in the US over the past decades and is making crucial contributions to the program today. This record on innovative and outstanding performance justifies the budget increases we have requested.

2 LBNL Role in U.S. HEP program

The goal of the LBNL HEP effort is to advance and support the U.S. HEP program through the maximum usage of the unique capabilities available in a large national laboratory closely tied to a major university. LBNL staff and U.C. Berkeley faculty work closely together utilizing the excellent engineering and fabrication facilities and state-of-the-art computing resources available at the Laboratory and the large number of excellent graduate and undergraduate students who are part of the University.

Major HEP experiments require the fabrication and operation of complex particle detectors and the manipulation of huge sets of data, and LBNL, working in collaboration with numerous universities, is playing a major role in several of these experiments, including CDF, BaBar, ATLAS and SNAP. At the same time, while LBNL does not operate a large HEP accelerator facility, it carries out a substantial accelerator R&D program, and collaborates with HEP accelerator laboratories in the construction of new facilities. LBNL invented the concept and initiated accelerator studies for the asymmetric B factory and collaborated with SLAC and LLNL in building PEP-II. There is presently a collaboration with Fermilab, Brookhaven, and CERN in building the high luminosity interaction regions of the LHC, as well as a collaboration on future accelerators including potential upgrades of LHC and the Linear Collider. LBNL is leading the SNAP program to determine the characteristics of the Dark Energy.

LBNL's role has been one of physics from 'start to finish'. We participate in the conception, design, construction, commissioning, operation, physics analysis and preparation of upgrades in our experiments. The support and facilities of the Laboratory allow us to carry these roles very effectively in a way not possible even in large university groups.

LBNL has played a major role in the development of large detectors for Fermilab, SLAC and the LHC. Itwas a lead institution in bringing the silicon strip vertex detector technology in CDF. This work had major impact on the top quark discovery, and led to the use of silicon trackers in virtually all collider detectors. LBNL, in collaboration with others, developed several of the crucial readout chips. At the same time it designed and built mechanical systems for both the DIRC particle ID and the SVT silicon systems and was responsible for SVT final assembly and installation. LBNL has taken leadership responsibilities in both the silicon strip system and the extremely challenging pixel system, and is collaborating with many university groups on their construction. LBNL responsibilities include both electronic and mechanical aspects, and again engineering support is playing an essential role.

2 Physics Division Programs

2.1 Discovery of the Origin of Mass

Exploration of the origin of mass plays a central role in the LBNL physics program. At the present time, the CDF experiment at the Tevatron forms the center of this program through a program of precision measurements of electroweak parameters. In 2007, the ATLAS experiment at the LHC will become the premier facility for such exploration. Further in the future, the Linear Collider will complement LHC research.

2.1.1 CDF

Members of the CDF group have leadership roles as convenors in four analysis subgroups: jet corrections, Higgs, B-tagging and semi-leptonic B physics. The group has contributed to W and Z cross section measurements and on the Z asymmetry to compare with Standard Model predictions.

An LBNL postdoc has carried out a search for a stable SUSY particle, the stop, with other members of the collaboration. Preliminary results on a mass limit have been shown at HEP Conferences. Also an LBNL PHD student has carried out a study of MSSM Higgs production in Run I. A measurement of the top cross section using silicon-vertex tagging has been submitted to PRL. This is the subject of another LBNL PhD student.

2.1.2 ATLAS

LBNL has been a pioneer in the development of new silicon detector technologies for high-luminosity hadron colliders. The LBNL group is continuing this role and is currently leading the U.S. effort to develop and fabricate silicon pixel detectors for ATLAS. The design of the critical front-end integrated circuits for the ATLAS pixel detector is largely an LBNL responsibility. LBNL also has the major responsibility for the design and fabrication of the pixel thermal and mechanical structure, which has required the development of new concepts. The overall support structure for the pixel system is an LBNL responsibility as is fabrication of about one-third of the active detector elements, modules, and the corresponding mechanical supports.

In addition, LBNL, in collaboration with the University of California (Santa Cruz), has produced and tested about one-third of the silicon strip detector modules for the central (barrel) region of ATLAS. A sophisticated system has been designed and fabricated at LBNL for testing the large number of integrated circuit wafers for the ATLAS silicon strip detector. This test system has been used at Santa Cruz, CERN, and RAL to cope with the testing of the large volume of integrated circuits that are needed for the ATLAS silicon strip system.

The LBNL group has had a seminal role in understanding the physics signatures at high luminosity hadron colliders. This work began in the 1980's and is continuing now for ATLAS. LBNL has a coordinating role in the development of the ATLAS physics simulation program. This ensures a close tie between the technical aspects of the experiment and the rich physics potential of the LHC.

The software and computing expertise available at LBNL is now being utilized to lead the development of the framework code (ATHENA) that will provide the backbone of the ATLAS software. This work builds on the experience of CDF and BaBar, and takes advantage of the strong team of physicists and computing professionals that has been brought together at LBNL.

2.1.3 Linear Collider (LC)

The Berkeley group has participated in the development of the community consensus in favor of the LC over the past few years. Marco Battaglia has initiated a new R&D effort on silicon detectors for the LC. In addition, we have been active in studies of TPC hardware for application at LC. We have collaborated with nuclear physicists interested in upgrades of the STAR experiment at RHIC in order to form a critical mass of researchers in this area.

2.2 Quark and Lepton Flavor Studies

2.2.1 BaBar

LBNL has played a major role in all aspects of the BaBar experiment beginning with the insightful proposal to use asymmetric beams to make precise measurements of CP-violation in B decays. During the construction phase, LBNL had responsibility for the Silicon Vertex Tagger (SVT), the Detector of Internally Reflected Cherenkov light (DIRC) and the Trigger and Drift Chamber Readout. In addition, LBNL led the original development of code for track reconstruction and was responsible for much of the software framework. Most recently LBNL led the design and implementation of a new computing model which has significantly increased analysis speed and has permitted the collaboration to increase its physics productivity.

The physics analysis effort is stimulated by the large data sample already collected, with more B meson data than CLEO collected in nearly two decades. The present LBNL analysis is focused on the following topics: $\sin 2\beta$, B mixing and tagging; charmless, quasi-two-body B decays, including first evidence of the decay to ϕK^+; form factors in semi-leptonic $B \to Dl\nu$ decay; rare tau decays to $\eta K\nu$, $\eta\pi\nu$; branching fractions for double-charm decays, $B \to \bar{D} - D_s^+$;
longer-term studies of nonleptonic decays with second class current suppression, including the first observation of $B \to a_0\pi$; and measurement of the angle alpha in $B \to \rho\pi$ decays.

2.2.2 CDF

At the Tevatron, there remains unique physics to be done in the area of CP violation, CKM matrix element measurements and many measurements of properties of B hadrons. The LBNL group has been heavily involved in the area of B physics analysis for many years, contributing to detection of several B decay modes and to mass and lifetime measurements (including the B_s lifetime). Marjorie Shapiro is currently the convenor of the B Physics Group. LBNL has also contributed to work towards measurements of B_d mixing and observation of time dependence of mixing. In Run II the LBNL initial physics interest is centered on precision measurements of CKM matrix parameters. The main analysis is a measurement of the hadronic moments of semileptonic decays of charged B mesons which provide constraints on QCD corrections to $|V_{cb}|$. This puts to use the expertise of the group, including detailed knowledge of the hadronic trigger that uses the SVT, and prepares the group for more complex measurements later on. In preparation for B_s mixing studies, the LBNL group has been working on full reconstruction of B_s decays.

2.2.3 KamLAND

The persistence of deficits in solar neutrino experiments and the impressive results from Super Kamiokande on atmospheric neutrinos was the impetus for new, higher sensitivity measurements of neutrino oscillations. The KamLAND experiment exploited the old Kamiokande underground site and the presence in Japan of large nuclear power rectors. The substantial investment ($20M) made by the Japanese government provided a firm basis for the development of this experiment. The LBNL-led US KamLAND Collaboration proposed several initiatives designed to make this experiment robust against potentially crippling backgrounds and to increase its sensitivity still further, enabling it to eventually measure directly solar neutrinos from ^{7}Be.

The one kiloton liquid scintillator target/detector results in approximately 750 neutrino events per year from the reactors, though they are 140 to 200 km away. The very large ratio of this distance to the neutrino energy enables KamLAND to reach two orders of magnitude further in Δm^2 than any previous reactor experiment, making it the first terrestrial experiment to address the solution to the solar neutrino problem. LBNL's contribution to the experiment, in addition to management and oversight (with UCB) centered on specialized waveform capture electronics ideally suited to KamLAND's needs. LBNL is also completing the construction of a new calibration system for the detector.

2.3 Dark Energy and Dark Matter

The impact of Berkeley astrophysics programs has been tremendous. It has been humbling discovery that 95% of the universe is composed of dark mater and dark energy, neither of which is described by our Standard Model. At the same time it gives us a clear focus.

2.3.1 ***Supernova Cosmology Project and the Nearby Supernova Factory***

The LBNL Supernova Cosmology Project was the first group to show how distant supernovae could be discovered on a reliable basis and that their brightness and redshift could be properly interpreted to measure fundamental cosmological parameters. Their data gave the first evidence that the geometry and fate of the Universe do not conform to expectations. These astonishing conclusions are the impetus for further studies to reduce systematic errors and to probe more deeply the physics that underlies these phenomena. LBNL scientists are working with other groups to study supernovae at high redshift using ground-based telescopes and the Hubble Space Telescope. At the same time, more low-redshift type Ia supernovae are needed for systematic studies and a broad effort for this is already underway.

The Nearby Supernova Factory *(SNfactory*) has been designed to lay the foundation for current and next generation experiments to determine the properties of Dark Energy. It will discover and obtain lightcurve spectrophotometry (simultaneous broadband lightcurves *and* spectral time series) for more than 300 SNe Ia supernovae in the low-redshift end of the smooth Hubble flow. Their statistical power alone will lower the statistical error of the current SCP results by up to 50% and will help reduce the systematic error. In the longer term, they will improve *SNAP*'s constraint on Ω_M by 40% and on w_0 by a factor of two. The SNfactory is now operating its search pipeline using the Quest camera on Mt. Palomar and it is commissioning a new spectrograph (SNIFS) on the University of Hawaii 2.2 m telescope.

2.3.2 SNAP

With a 2m telescope and 600-million pixel imager, SNAP (Supernova/Acceleration Probe) could discover and obtain high-signal-to-noise calibrated light-curves and spectra for over 2000 Type Ia supernovae at redshifts between $z = 0.1$ and 1.7. This would help eliminate possible alternative explanations, give experimental measurements of several other cosmological parameters, and put strong constraints on possible cosmological models. The imager would use the CCD developed by the Physics Division. These CCD's have a high resistivity substrate with excellent quantum efficiency at long wavelengths. Their development was a direct spin-off of previous investments in SSC detector technology.

For the past 4 years, LBNL has carried out a broad program of R&D to define the science case for SNAP and to develop the technologies needed to realize the program. In November 2003, NASA and DOE announced a Joint Dark Energy Mission (JDEM) for which SNAP appears to be a natural choice. LBNL scientists are members of the Science Definition Team for JDEM. As this team begins its deliberation, the plan and schedule for these studies will become more clear.

2.3.3 Cosmic Microwave Background

The physics division has set new long term goals for the CMB program, which will cumulate, in a precise characterization of the CMB polarization. This will provide insight on the early phase of inflation—a key element in the puzzle of understanding dark energy. A diverse team of both young and experienced innovators has been assembled to address these challenges, in a strong partnership with UCB campus and NERSC. LBNL's flagship CMB polarization experiment is POLARBEAR, which is a ground-based CMB observatory to be built in two stages over the next 3-5 years. POLARBEAR has the potential to probe GUT scale energies of 10^{16} GeV, by detecting the fingerprint that inflationary gravity waves (IGW) leave on the curl-component of the polarization. It will make precision measurements of the polarization signal down to angular scales of an arcminute, allowing it to precisely measure the cosmic shear signature. Cosmic shear carries information about the matter distribution and neutrino masses—and must be well understood to measure the IGW signal. On the road to these discoveries, LBNL is developing the instrumentation to be used in POLARBEAR through participation in two key CMB experiments being constructed to perform large scale surveys of galaxy clusters with the Sunyaev Zeldovich (SZ) effect, APEX-SZ (2004) and the South Pole Telescope (2006). Galaxy clusters can be used as test masses to trace the expansion history of the universe, allowing for independent confirmation of the SN1a acceleration results using a different technique with different systematics.

Complementing these instrumentation advances is a vigorous theory and data analysis effort. Currently it is focusing on the analysis of MAXIPOL (the polarization sensitive successor to MAXIMA) data and the development of algorithms for the analysis of the Planck satellite data. The new science and the large data sets expected from APEX-SZ, and POLARBEAR will require an expansion of our theory effort.

2.4 Theory

The Particle Theory Group, including its LBNL and Berkeley campus components, is one of the world's leading research groups and an important center for the training of students and postdoctoral fellows. The traditional coherence of theoretical research with the experimental program of the Physics Division is a special strength of the LBNL group. Research is carried out in the Theory Group over a very broad range of subjects, ranging from M-theory to phenomenological studies of immediate importance to experiments, especially ATLAS and BaBar. Recent work by Berkeley theorists and their collaborators on the possibility that there are extra macroscopic dimensions has inspired a profusion of new investigations throughout the field.

2.5 Particle Data Group

The Particle Data Group provides essential up-to-date summaries of experimental and theoretical particle physics to the HEP community and other physicists and to teachers and students. LBNL is the headquarters of a large international effort to provide compiled and evaluated information on particle properties and related areas, as well as reviews, tables, plots, and formulae. The PDG consults with over 700 physicists from every major particle physics institution in the world to obtain expertise on data and specialized topics, and to insure that the summaries reflect the current viewpoints of the community. An international advisory committee reviews all publications and operations annually. The information is made available through the biennial publication of the "Review of Particle Physics" (an 800-page book), and the "Particle Physics Booklet."

The Particle Data Group has a large impact in science education and awareness. The "Review" and "Booklet" are used by thousands of students and teachers. The PDG collaborates on several educational projects including the QuarkNet program, the Contemporary Physics Education Project, the award-winning "Particle Adventure" website, the CDROM-based exhibition version, the "Quark Adventure," and the Nobel Foundation's Nobel Electronic Museum. These projects make particle physics accessible to non-scientists and enable high school and college teachers to use particle physics in introductory physics courses.

3 Future Directions for the Berkeley Program

The future program at Berkeley can be reliably extrapolated from the natural development of the ongoing activities. Our physics future will increasingly focus on discovery of the origins of mass, and on determining the nature of the Dark Energy. We plan to maintain the diversity of our program with a complimentary effort in neutrino physics. ATLAS and SNAP have become the largest components of the Physics Division program. Neutrino experiments will be a joint effort with the Nuclear Science Division. R&D efforts for both instrumentation and computing will be ongoing. The Linear Collider accelerator efforts will grow commensurate with the national linear collider collaboration.

The Physics Division Strategic Plan describes the planning assumptions and our future plans. The assumptions we made for planning purposes are shown in Figure 1. Key dates and elements of the LBNL program are shown in Figure 2. We have already made significant adjustments in resources to match these priorities.

In the Physics Division the accelerator-based efforts can be mounted in scenarios with modest budget increases. However, an increased involvement in LC, additional efforts in neutrinos, or effort on other large new accelerator-based projects would require a restoration of buying power to the Division's budgets. For the particle cosmology program, additional funding will be required. R&D support of future efforts, both accelerator-based and non-accelerator-based, should be restored in parallel with strengthening the existing efforts in an increased buying power scenario. Our traditional contributions to the community should be maintained. In the following sections, we provide more details on each of the elements of our future HEP program.

3.1 Cosmology

Recent studies of high redshift type Ia supernovae (SNe) observed with the Hubble Space Telescope (HST) and ground-based telescopes confirm the Supernova Cosmology Project's (SCP) well known 1998 result, which, based on a sample 42 type Ia supernovae, excludes a simple Ω_M =1 flat universe and presents strong evidence for the existence of a cosmological constant (Ω_Λ>0). To fully exploit the use of SNe Ia as cosmological probes and to study the ``dark energy" that is causing the acceleration of the universe's expansion, a space-based telescope such as SNAP is needed. The conceptual design and requisite R&D for such a space mission form a large part of our program. For continued studies of SN Ia cosmology while SNAP is being prepared, the SCP will continue its program of supernova search/identification/and follow-up campaigns in the mid- to high-redshift region employing coordinated multi-epoch observations using the most powerful ground-based telescopes and the Hubble Space Telescope (HST). However, these high redshift studies will be completely dominated by known and potential systematics unless SNe Ia are better calibrated and scrutinized far more closely for (as yet undetected) systematic effects and towards this end we are developing the Nearby Supernova Factory (SN Factory) which will provide a major improvement on the low-z end of the Hubble diagram ($0.03 < z < 0.08$) by providing a substantial increase in statistics and greatly improved control of systematics.

3.1.1 Supernova Cosmology Project and the Nearby Supernova Factory

The goals of SCP program are to add statistics to the middle region of the Hubble diagram ($.3 < z < .8$) and extend it to $z > 1$. Prior to SNAP, such studies can provide a measurement of the dark energy equation of state, $\langle w \rangle$ (time average) that is limited in precision, but may still be able to distinguish a cosmological constant ($w = -1$) from alternative models. The SCP is collaborating with a major five-year legacy survey using the Canada-France-Hawaii Telescope that will yield hundreds of SNe Ia in the mid-redshift range.

A second focus of the current program is to use HST to study SNe with $z > 1$. Though the statistics of these very high SNe will necessarily be small due to the limited field of view of the HST, such events will be of great interest as they allow us to look back to the acceleration/deceleration transition era.

The Nearby Supernova Factory *(SNfactory)* is designed to lay the foundation for current and next generation experiments to determine the properties of Dark Energy. It will discover and obtain lightcurve spectrophotometry (simultaneous broadband lightcurves *and* spectral time series) for more than 300 SNe Ia supernovae in the low-redshift end of the smooth Hubble flow. Their statistical power alone will lower the statistical error of the current SCP results by up to 50% and will help reduce the systematic error. In the longer term, they will improve SNAP's constraint on Ω_M by 40% and on w_0 by a factor of two. This SNe dataset will further serve as the premier source of calibration for the SN Ia width-brightness relation and the intrinsic SN Ia colors used for correction of extinction by dust (needed by SCP and SNAP). This dataset will also allow an extensive search for additional parameters, which influence the quality of SNe Ia as cosmological probes. Well-observed nearby SNe Ia, especially in host galaxies spanning a wide range in star-formation histories, are essential for testing for possible systematics. Following the commissioning of SNIFS in early 2005, the project will be ready to carry out its program of supernova studies.

3.1.2 SNAP

In November 2003, NASA and DOE announced an agreement to fund a Joint Dark Energy Mission (JDEM) with a competitive process to select a mission in 2006. This decision has significantly changed the course of the SNAP program at LBNL and within the collaboration. NASA and DOE has formed a Science Definition Team and LBNL will be very active in that effort. Three LBNL scientists from SNAP are on the team and they will be supported by the simulation efforts within the SNAP collaboration. In addition, the SNAP detector R&D effort is now critically important.

The SNAP science hinges on the reach to high redshift supernovae and precision weak lensing measurement only achievable in space. Realization of the science requires state-of-the-art photodetectors in the visible to near infrared (NIR) wavelengths (0.35 – 1.7 μm). A DOE review noted that this is "the most ambitious detector focal plane ever proposed, for ground or space." With the investments we are making in the R&D period, we can advance these devices into the enabling technologies required for the SNAP science program. If we fail to ready these technologies in time the science reach of SNAP will be compromised and its ability to successfully compete for JDEM will be seriously weakened. The recent technical review in Nov. 2003 by outside experts emphasized this point: "With the recent re-direction to JDEM, it is very important to re-focus and heavily emphasize work on advancing key technologies. Detectors and electronics are likely *the* highest risk area in the mission concept. The visible arrays, and especially the near-IR arrays, are not in the bag." To set the scale of this ambitious program, the IR system that we are proposing contains more devices than are currently deployed on ground-based systems. We realize that serious failure in the R&D program would result in significant loss of science or worse. Likely we would have to consider a much smaller focal plane with the potential elimination of wavebands (visible or infrared) and loss of the dark energy science of greatest interest.

The SNAP team has continued to refine and focus the R&D program. Instead of a Conceptual Design Report for a CD1 review conducted by DOE, our efforts are now focused on developing the science, the technologies, and the concepts in time for the JDEM Announcement of Opportunity, to be issued and competed by DOE and NASA. The overall scope of the R&D

program has been refined to take into account the process by putting enhanced effort into simulations to understand various mission concept trade-offs. These studies will be key inputs to the JDEM Science Definition Team. We are carrying out an optimization across the total scientific mission, including the telescope, focal plane, and science simulation to establish scientifically driven requirements. This integrated approach to Dark Energy science is the focus for the SNAP R&D period.

3.1.3 Cosmic Microwave Background

CMB observations have moved from relatively small experiments using a few noise limited sensors to a precision science employing large sensor arrays to provide the required sensitivity. LBL is in a unique position to take a leadership role in the development of instrumentation for the next generation of CMB observations. Having characterized the CMB temperature anisotropy, CMB science is taking the next observational step by measuring the polarization anisotropy and small angular scale CMB secondary effects, such as the Sunyaev Zel'dovich effect and cosmic shear. These measurements have the potential to provide insights into the expansion history of the universe that are perhaps even more exciting and ground breaking than the revolutionary insights provided by the temperature anisotropy. The CMB effort can be split into two categories: instrumentation and theory plus data analysis.

The primary focus for the current stage is instrumentation for experiments with large format bolometer arrays. APEX-SZ and the South Pole Telescope will utilize the Sunyaev-Zel'dovich (SZ) effect to search for distant galaxy clusters. The distribution of galaxy clusters vs. redshift is sensitively dependent on Ω_M, Ω_λ, and w. Unlike x-ray or optical surveys, the magnitude of the SZ signal is independent of redshift, so it is well-suited for deep searches. These experiments are complementary to SNAP as they attack the same physics with a completely different technique. The flagship LBL-based experiment, POLARBEAR, aims at detecting gravity waves generated by inflation, which could manifest themselves as a net curl in the polarization field of the CMB (commonly referred to as B-modes). CMB polarization is the only probe known to be sensitive to this inflationary fingerprint.

The instrumentation developments for POLARBEAR are a stepping stone towards the technology that will ultimately (post-SNAP timescale) be deployed on a CMB satellite mission, which is foreseen as one of NASA's Einstein probes. Our team includes a co-Investigator and three collaborators on a NASA proposal to develop a CMB polarization mission. Participation in this mission is a natural progression for both SNAP and CMB personnel on a timeframe beyond 2009.

The second category for the CMB effort is data analysis and CMB phenomenology, for which the physics division has nurtured a successful partnership with NERSC. This effort is growing, with LBL playing an important role in the analysis of MAXIPOL (the successor to MAXIMA) data and in preparing algorithms for the ESA Max Planck Surveyor satellite mission, APEX-SZ, and POLARBEAR. The future for CMB polarization may well be a satellite mission, on a timeframe that follows SNAP. LBNL is positioning itself to play an important role in the design and data analysis of a future CMB polarization satellite.

3.2 Discovery of the Origins of Mass

3.2.1 ATLAS and LHC-ARP

The ATLAS collaboration has started to plan for the pre-operation, operations and research phase of ATLAS. The LBNL construction responsibilities for the silicon strip detector are complete. It is planned to assemble the overall pixel system at CERN starting at the end of 2005. Thus a major part of the LBNL ATLAS work will shift to CERN from early 2005 through 2006 in order to assemble, install, commission and first operate those parts of the ATLAS detector that are LBNL responsibilities. Beyond 2007, LBNL will be required to assume operations and maintenance responsibilities for aspects of the pixel detectors. This will require the continued involvement of technical personnel in both the mechanical and electronics aspects of these detectors, in addition to physicists. A continuous presence at CERN by LBNL personnel will be necessary to fulfill these responsibilities. Similarly, support of the initial operations of the framework code and other software developed at LBNL will be critical to the success of ATLAS in its first years of operation. LBNL computing professionals will be needed to provide this support and are resident now at CERN.

The number of physicists at LBNL involved in the ATLAS will continue to grow. We anticipate a modest growth in the number of faculty and senior physicists but a more substantial growth in the number of postdoctoral physicists and graduate students.

Although completion of the ATLAS detector is still some years away, concepts for upgrades are already under discussion. A major area for potential upgrades is in the tracking detector. The ATLAS design allows the silicon pixel detector to be removed and installed without disturbing substantially the remainder of the tracking detector. One can already foresee the desirability of improvements (e.g. finer granularity, improved radiation hardness, lower mass) to the pixel detector, and R&D to this end should begin already in 2005 if one is to be ready to install improved detector elements after the first few years of ATLAS operation.

3.2.2 Linear Collider

We expect the Linear Collider will be the next International Accelerator Facility to be built. Our efforts on silicon detectors and Time Projection Chambers will continue and will grow as effort on BaBar winds down. Berkeley will make both physics and technical contributions to this facility where we have key technologies to offer.

3.2.3 CDF

The effort on CDF will decrease substantially over the next few years as part of the Physics Division Strategy to move resources to ATLAS. Postdocs will not be replaced as they reach the end of their appointments. The group, however, will maintain a reduced program at Fermilab through 2007. Studies of top quark properties will continue. To this purpose the group has heavily contributed to the development and optimization of the b-tagging algorithm. The group has concentrated on analyses that use b-tagging. Work on the top mass measurement, using events with a tagged b jet, will continue. A new method for determining the top mass is being developed by an LBNL postdoc, with contributions from other members of the group. The aim is to reduce the statistical error by using a novel likelihood procedure.

3.3 Quark and Lepton Flavor Studies

3.3.1 BaBar

The LBNL BaBar Group will continue to be active in the experiment until 2008. The group will continue to work on a number of analysis topics. There are great opportunities at BaBar with the prospects for 500 fb^{-1} by the end of 2006. This will permit the collaboration to resolve the discrepencies in sin 2 beta in different channels, make a high-precision measurement of alpha, make a measurement of gamma with moderate precision, make a precise determination of $|V_{cb}|$ and $|V_{ub}|$, explore the D and D_s and X(3872). It addition, it will be possible to study strong dynamics in weak decays (e.g. B -> VV) and to search for new physics in B-> $X_s$ll.

3.3.2 CDF

We have begun a vigorous program to exploit the physics opportunities in RUN II. The LBNL physics interest is centered on precision measurements of CKM matrix parameters. Observation and measurement of B_s mixing and determination of x_s is a hallmark measurement for CDF. In order to resolve these oscillations at large x_s, the proper decay length of B_s must be determined with high precision. This forces CDF to use fully reconstructed decays for the measurement.

3.3.3 Neutrino Physics

Important upgrades are planned to allow KamLAND to be sensitive to solar neutrinos. Strong support from the US-Japan agreement is anticipated to help carry out this effort. The solar neutrino measurements place stringent demands on backgrounds, requiring purification of the scintillator oil. LBNL's Physics and Nuclear Science Divisions support this effort jointly. Possible construction of a National Underground Laboratory is an important opportunities for neutrino physics in the future. Recently, we have obtained support through LDRD to investigate the possibility of a θ_{13} reactor experiment.

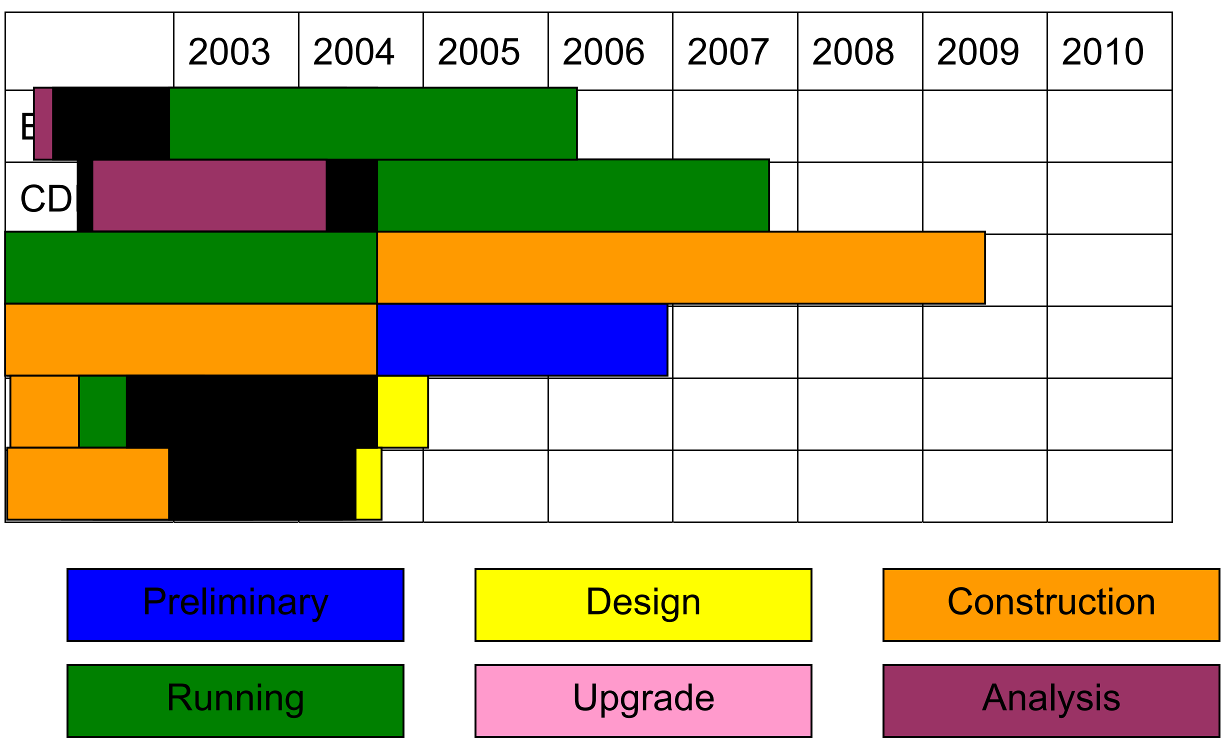
4 Conclusion

LBNL has helped to shape high energy physics in the US over the past decades. It has transformed hadron collider physics with the SVX at Fermilab, proposed building an asymmetric electron-positron collider, and then was a major partner in the PEP-II construction and in the design and construction of BaBar, led the development of smart pixel technology for the LHC, and opened the field of supernova cosmology. This record of innovation and outstanding performance justifies increases in the base program budgets.

Figure 1: Planning assumptions

SNAP CD-0 submitted	2004 (In preparation)
JDEM CD-1	2006
LC Approval	2007
LHC Commissioning	2007
ATLAS Physics Run	2008
JDEM Launch	2014

Figure 2: Program Elements



Appendix III

Table 1 shows the Physics Division budget by major expenditure category. Table 2 shows the heads per group.

Table 1: Base Budget by Project

Project Information	FY04 funding	FY05 allocation	
ATLAS	3362	3600	7%
CDF/D0	1859	1570	-16%
Neutrinos	472	350	-26%
BaBar	2212	1970	-11%
Linear Collider	126	232	83%
Theory	2037	1950	-4%
PDG + QuarkNet	1440	1300	-10%
SCP/SNF	2158	2355	9%
Cosmology Theory/INPA	273	325	19%
CMB/Detectors	691	710	3%
SNAP	8463	7865	-7%
Totals	23094	22227	-4%
Holdback		93	
Initial Fin Plan		22320	

Table 2: FY03 Staff by Head Count

Staff levels (FTE's) Physics

	BASE	career-sr.staff	career-staff	term	faculty	total: physicists/computer scientists	engineers	technical support	admin	GSRA /students	retirees, others	TOT
FY02	TOTAL	18.6	7.4	26.9	3.3	56.2	8.6	9.7	0.0	12.6	2.6	89.7
	CDF	1.3	1.0	7.0	0.2	9.5				4.9	1.0	
	E871			2.0	0.2	2.2				0.2	0.1	
	D0	1.0		2.0	0.2	3.2				0.5		
	BABAR	4.1	2.0	5.8	0.4	12.3	0.1	2.8		3.1	0.3	
	ATLAS	4.5	2.0	2.2	0.1	8.8	6.5	0.9		0.1	0.2	
	SNAP/SCP	1.1	1.4	4.0		6.5	2.0	1.0		1.9	0.2	
	other astro physics	1.0		0.8	1.1	2.9						
	LHC accelerator					0.0						
	Accelerator R&D					0.0						
	Theory/PDG	4.0	1.0	3.1	1.1	9.2		3.0		1.9	0.3	
	MSL/Detector Development/Other	1.6				1.6		2.0			0.5	
FY03	TOTAL	17.0	8.0	25.3	3.6	53.9	6.0	8.9	0.0	12.8	3.1	84.6
	CDF	1.3	1.0	6.9	0.3	9.5				4.6	0.1	
	E871			2.0	0.2	2.2					0.1	
	D0	1.0		1.0	0.2	2.2				0.5		
	BABAR	2.5	2.6	4.8	0.4	10.3				3.1	1.2	
	ATLAS	3.3	2.0	2.1	0.0	7.3	4.0	3.9		0.8	0.7	
	SNAP/SCP	2.6	1.4	3.8		7.8	2.0	1.0		1.9	0.2	
	other astro physics	1.0		0.8	0.9	2.7						
	LHC accelerator	2.1			0.3	2.4						
	Accelerator R&D					0.0						
	Theory/PDG	2.8	1.0	3.0	1.3	8.1		2.0		1.9	0.6	
	MSL/Detector Development/Other	0.5		1.0		1.5		2.0			0.3	
% change (FY02 to 03)		-8.6%	8.1%	-5.8%	7.6%	-4.1%	-30.2%	-8.2%		1.5%	18.5%	-

FY04	TOTAL	20.7	7.5	24.9	3.5	56.5	16.9	13.8	0.0	13.8	2.5	103.5
	CDF	1.2	0.5	4.0	0.2	5.9		0.0		3.6	0.0	
	Neutrino Research	1.0		1.0	0.2	2.2					0.1	
	D0	0.5			0.2	0.7				0.1		
	BABAR	3.2	0.0	4.2	0.8	8.2		1.5		1.8	0.2	
	ATLAS	6.5	0.0	5.0		11.4	2.0	3.0		1.11	1.6	
	SNAP/SCP	3.9	2.8	5.0		11.6	14.9	5.4		3.4	0.1	
	other astro physics			1.8	1.1	2.9					0.1	
	LC	0.5				0.5						
	Accelerator R&D					0.0						
	Theory/PDG	2.5	4.2	4.0	1.1	11.8		1.9		3.7	0.5	
	MSL/Detector Development/Other	1.5				1.5		2.0			0.1	
FY05	TOTAL	19.3	12.2	32.5	4.0	68.0	10.4	3.0	1.0	8.3	2.6	93.4
	CDF	1.0	0.7	2.0	0.2	3.9				3.3	0.0	
	Neutrino Research	1.0		2.0	0.2	3.2					0.1	
	D0	0.3			0.2	0.5						
	BABAR	4.2	0.0	4.0	0.4	8.6				1.0	0.2	
	ATLAS	4.5	2.0	6.2		12.7	1.8	2.0		1.21	1.7	
	SNAP/SCP	2.8	5.8	12.0	0.9	21.5	2.4	1.0		0.9	0.1	
	other astro physics				0.8	0.8					0.1	
	LC	0.5			0.3	0.8						
	Accelerator R&D					0.0						
	Theory/PDG	2.5	3.3	5.0	1.1	11.8			1.0	1.9	0.5	
	MSL/Detector Development/Other	2.5	0.5	1.3		4.3	6.3				0.1	
% change (FY04 to 05)		-6.8%	62.7%	30.8%	15.5%	20.3%	-38.3%	-78.3%		-39.6%	5.2%	-

head count, July 2004										
CDF	1		5	1	7.0				6	
Neutrino Research	2		1	1	4.0		1		1	2
D0	1			1	2.0					2
BABAR	5		3	1	9.0				5	3
ATLAS	4	4	6		14.0		4		4	2
SNAP/SCP	3	2	10	2	17.0		1		4	1
other astro physics	1			4	5.0					
LC	1				1.0					
Accelerator R&D					0.0					
Theory/PDG	2	3	4	9	18.0		2	1	9	8
MSL/Detector Development/Other	2		1	1	4.0					1
	22	9	30	20	81	0	8	1	29	19